Maximus' Hydronic Heating System

This document describes how my hydronic system is designed and how I intend it to work. The concepts, materials and descriptions herein relate directly to my hydronic system diagram on page 3. This system has some integration with the thermal sensor/actuator bank in the control center which is not heavily reverenced herein..

Key parts of the system;

- Coolant system on my 2004 F350 6.0l diesel engine (via the heater hose connections)
- 5kw diesel coolant heater (Chinese copy of an Espar D5)
- SureCal 20l 'Calorifier' (5.28 gallon insulated water tank w/ 120V/1kW heater & coolant HX)
- 1l expansion tank for cabin heater (from Cooper Mini)
- Bunk heat exchanger (5x5x1 heater core with 120mm fan and KSD 1600, 40C thermal switch)
- Main heat exchanger (10x5x1 heater core w/ 2-120mm fans and KSD 1600, 40C thermal switch)
- Shower heat exchanger (3/4" and 1/2" copper pipe, 8 rung 'ladder' towel heater)

Piping system

- 3/4" heater hose coolant loop that connects all the systems main components
- 5/8" heater hose connections at the calorifier
- 1/2" PEX pipe coolant circuit to main & shower cabin radiators and floor tubing circuit
- 3/8" PEX pipe coolant circuit to bunk cabin radiator and 2 freeze protection circuits

Fittings

- ¾" ProPEX plastic tees & MPT adapters, 3/4" brass barbed bulkhead, Oetiker 30.1mm single ear SS cinch clamps (for 3/4HH)
- ¾" PEX crimp MPT adapters, Oetiker 27.1mm cinch clamps (for 5/8"HH)
- ¾ " & ½" copper sweat, reducing tees, elbows, MPT adapters, FPT adapters & ball valve (for shower towel heater)
- ½" PEX crimp FPT swivel fittings, swivel tees, male adapters, ball valve & cinch clamps (for 1/2" PEX)
- ½" OD x ½" MPT adapter (for 3/8 PEX. All 3/8 PEX connections are OD)
- ¼" stainless and brass nipples, adapters, tees, elbows and auto-vents for radiators
- Loctite medium strength thread locker for sealant on threaded fittings

Control System

- 4 - US Solid 3/4" FPT motorized ball (CR02) valves for partitioning main coolant circuit
- 2 - 3 US Solid 1/2" FPT motorized ball valves (CR04) for controlling freeze protection
- 2 - 1/2" and 3 - 3/8" manual ball valves for balancing the cabin coolant flow.
- Four pole, five position rotary 'mode' switch for operation of the 4 main ball valves
- 2 - STC-3008 dual channel temperature controller to operate the freeze protection loops
- 9 x 18AWG cable to connect the rotary switch, valves and temperature controls

I want the system to do 4 things as selected by the rotary 'mode' switch;

Mode 1) 'Engine hot water' directs engine coolant to heat water in the calorifier while driving.

Mode 2) ‘Coolant heater hot water’ directs coolant heater output to the calorifier while stationary.

Mode 3) ‘Cabin heat’ directs coolant heater output to cabin radiators & freeze protection.

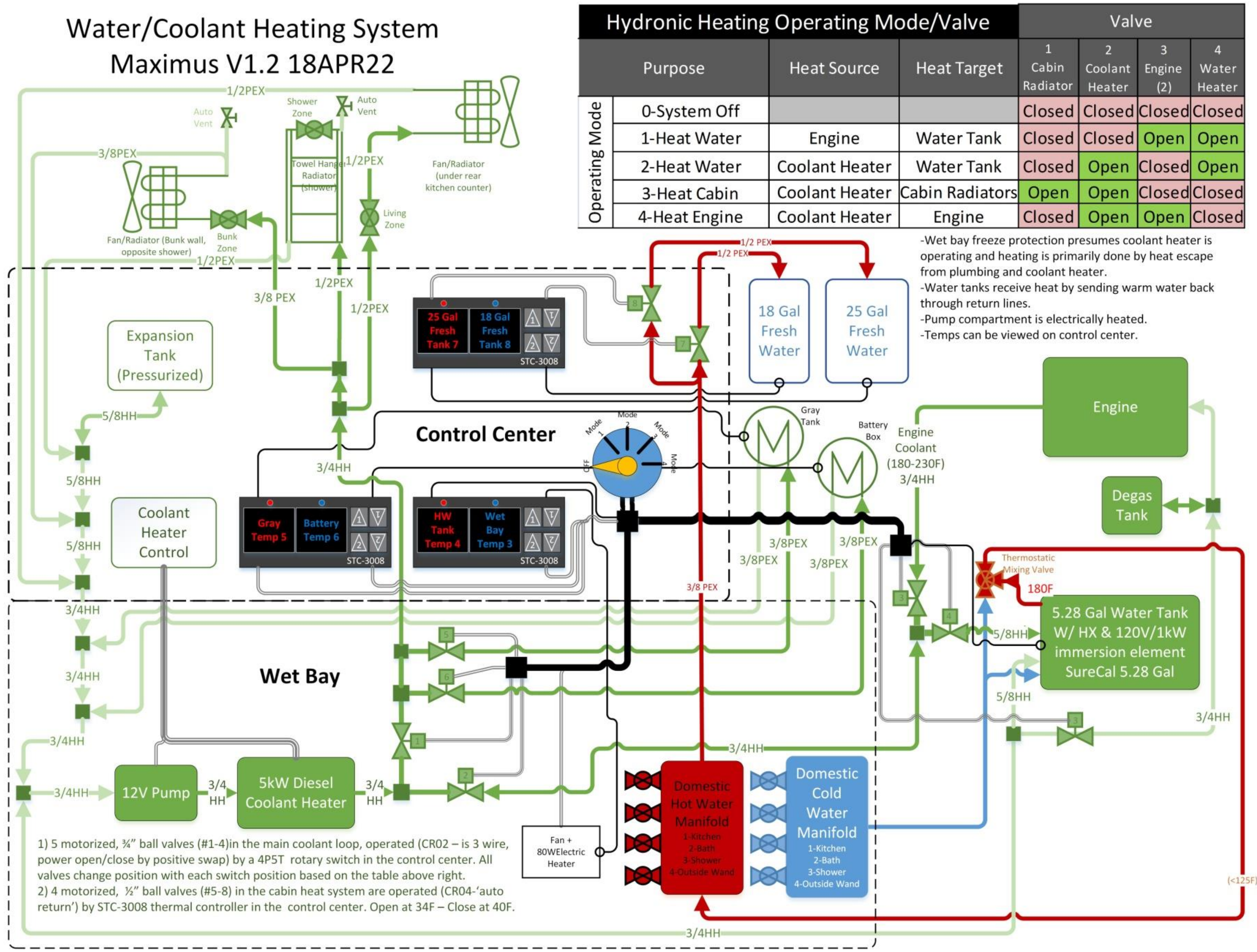
Mode 4) ‘Engine heat’ directs coolant heater output to pre-heat the diesel engine.

These four modes require that all parts of the engine, coolant heater, water tank and cabin heater all circulate the same coolant through different parts of the main circuit (3/4” HH, heater hose) to different equipment. The coolant systems for the engine and cabin could be completely separated by a fin-plate heat exchanger but I am satisfied with a single system design that is only ‘effectively’ and periodically, separate. The sequential operation of the mode switch, commands opening or closing each of the 4 valves within the coolant loop to connect only the need portions of the system at any one time. The unused sub-systems are removed from participating in coolant circulation.

Just controlling the supply side of the loop is enough to prevent the coolant from flowing to unused equipment but not enough to prevent the high pressure in any part of the system from being from being experienced in all parts. My engine cooling system runs at 15psi pressure and to prevent of the hydronic systems from being under that pressure, I installed valves on both engine supply and return lines (the same control signal can operate them simultaneously). The same argument applies if you are concerned about the hydronic system leaking and compromising the engine by losing coolant. If you want to guarantee against that, you also need two valves.

With 5 valves being needed to configure coolant flow, there are only 4 desirable settings for 16 possible combinations. Needing to recall and manually set them individually seems unlikely to be reliable. To implement a controlled, interlocked operation, the valves need to be electrically operated and use electrical interlocks (rather than mechanical) to switching in a manner that is convenient and consistent. A mechanical switch seems simple, reliable and adequate to do that.

Fig. 1: System Diagram - Coolant Circuits with Simplified Electrical



Hydronic Heating Operating Mode/Valve				Valve			
	Purpose	Heat Source	Heat Target	1 Cabin Radiator	2 Coolant Heater	3 Engine (2)	4 Water Heater
Operating Mode	0-System Off			Closed	Closed	Closed	Closed
	1-Heat Water	Engine	Water Tank	Closed	Closed	Open	Open
	2-Heat Water	Coolant Heater	Water Tank	Closed	Open	Closed	Open
	3-Heat Cabin	Coolant Heater	Cabin Radiators	Open	Open	Closed	Closed
	4-Heat Engine	Coolant Heater	Engine	Closed	Open	Open	Closed

-Wet bay freeze protection presumes coolant heater is operating and heating is primarily done by heat escape from plumbing and coolant heater.
-Water tanks receive heat by sending warm water back through return lines.
-Pump compartment is electrically heated.
-Temps can be viewed on control center.

1) 5 motorized, ¾" ball valves (#1-4)in the main coolant loop, operated (CR02 – is 3 wire, power open/close by positive swap) by a 4P5T rotary switch in the control center. All valves change position with each switch position based on the table above right.
2) 4 motorized, ½" ball valves (#5-8) in the cabin heat system are operated (CR04-'auto return') by STC-3008 thermal controller in the control center. Open at 34F – Close at 40F.

Appendix B: Hydronic Valve Electrical Schematic

The motorized ball valves are available with 7 different operating schemes (see appendix 1), the four most common and relevant are;

Type CR01 uses 2 wires with forward or reverse polarity to open or close.

Type CR02 uses 3 wires. 1 ground and separate ‘open’ and ‘close’ leads, to be powered for respective actions.

Type CR03 uses 3 wires. 2 for constant power and a third for signal with 12V power to open and no power to close.

Type CR04 uses 2 wires. Straight polarity power signals open, removing power discharges an internal capacitor to close under power.

To construct a system using two different control sources, I chose two different control types. The rotary switch has a single input which it connects, in series, to 5 (separate) outputs. The input is +12V and the output is connected to either the open or close lead from respective valves of a CR02 control. It is also possible to use a CR03 or CR04 type, (using ‘power’ or ‘no power’ signal) but CR02 is the most common control type. My second choice would be CR03 because it has constant power and therefore a more reliable powered close but it is very uncommon. CR04 is common but I am hesitant to rely on a storage capacitor for closing power if there is a possibility of needing more power for a difficult closing situation.

For the zone controls on the coolant loops, the SPST contacts of the STC-3008 thermal controller can only provide an ‘open’ signal by closing the relay contact and a ‘close’ signal by opening the contact. Without using additional equipment, this will only work with type CR03 or CR04. I preferred CR03 but only CR04 was available.

Fig. 2: Logic diagram showing the 5 operating modes and the corresponding coolant loop valve positions

Mode 0: All valves are closed. System is inoperative.

Mode 1: Heating potable water with engine coolant (most desirable and most frequent need) requires the valve to the engine and water tank to be open. The valve to the coolant heater and cabin needs to be closed to prevent coolant from bypassing the calorifier

Mode 2: Heat is not available from the engine nor needed for the cabin heat so both are closed. Heat is generated by the coolant heater and used by the water tank so those valves are open.

Mode 3: Cabin heat is needed from the coolant heater so both valves are open and unused sections are closed to prevent coolant bypass.

Mode 4: This is the most ‘connected’ between camper and truck engine of all modes but since the engine is off, risk is low. Calorifier and cabin heat are closed to prevent bypass.

The mode switch input only makes contact with one output at a time. In this way, each of the 5 valves can be set to be open or closed at each of the 5 positions the rotary switch is in. Because all 4 poles switch together, all 5 valves, change state together. This switch is a 'break-before make' meaning as the switch moves between positions, it disconnects from the terminal its leaving before it connects to the one it's approaching. Some rotary switches are 'make before break' which would apply power to the close and open wires at the same time which would be a problem.

Coolant Heating System Valve Operation				Valve			
	Purpose	Heat Source	Heat Target	#1 Cabin Heat	#2 Coolant Heater	#3 Engine (2)	#4 Calorifier
Mode Switch	0-System Off			Closed	Closed	Closed	Closed
	1-Heat Water (E)	Engine	Water Tank	Closed	Closed	Open	Open
	2-Heat Water (C)	Coolant Heater	Water Tank	Closed	Open	Closed	Open
	3-Heat Cabin	Coolant Heater	Hydronic Heat	Open	Open	Closed	Closed
	4-Heat Engine	Coolant Heater	Engine	Closed	Open	Open	Closed

None of the changes in mode switch position turn on or off the coolant heater. It must be started from its separate control panel manually when heat is desired, either before or after the mode selector is set. The default position for the mode switch should be '1' if water heating is desired when driving. The only time mode 0 is likely to be used is to respond to a leak or ensure the system can rest in a safe condition so that and undetected leak cannot cause a large coolant loss.

Freeze protection loops, made from 3/8 PEX tubing, will run from valves in the wet bay to loop through the gray tank and battery box. Being plastic, they are not very thermally conductive BUT they do not need to provide a lot of heat, raise compartment temperatures very high or do anything quickly. The heater will presumably be on long term for cabin heating needs and freeze protection can happen for that similarly, long term.

In the gray tank, the coil will be beneath the small, flat, bottom portion of the tank, needing to conduct heat through a relatively thin layer of fiberglass. The tubing will likely be attached with fiberglass or epoxy to the bottom of the tank to improve contact and conductivity. It will also pass through the side compartment containing the macerator pump. It might be possible to change the loop inside of the compartment to a copper or aluminum material if higher heat transfer is desirable (possible for the gray tank).

In the battery compartment, having the tubing remain non-conductive is desirable. Using a small, thermally activated fan to circulate air in even a small space could greatly accelerate heating and uniformity. If I use a fan, it will be constantly powered but operated locally by a normally open, (turns 'on' at high temp) 40C, KSD9700, thermal switch attached to the coolant line (comes on any time hot coolant flows and stays on till the tube cools off).

Hot coolant is provided to each freeze protection loop by a 1/2" motorized ball valve (even though it has a 3/8 line), from the supply side of the cabin coolant loop. Valves are operated by STC-3008 thermal controllers located in the control center with long wire temperature sensor placed in the monitored space. The control displays the current temperature and set point on an LED display. These are very cheap, (~$11 for 2 channels) and only have one single pole, single throw relay output. The relay can only supply or not supply 12V to operate our CR04 valve.

ADDITIONAL CONTROL ISSUES

1) Overheating the calorifier water is possible if high temperature engine coolant is circulated continuously. Heating water to 180F using 200-230 degrees engine coolant should take less than an hour. If driving for longer than that, engine coolant circulation needs to be shut

off to prevent overheating the water. If water temperature were to exceed, 100C/212F, it would begin to boil and increase water pressure. Even if the increased pressure were tolerated by the system, and prevented it from boiling, it would flash to steam as soon as pressure is released by opening an outlet tap. This is a potentially very dangerous situation.

Since the calorifier loses heat and water temperature drops over time, there will be a temperature sensor added to the tank exterior (under insulation) to monitor the water temperature for use in determining if it can be used directly or if the coolant heater needs to boost it. An STC-3008 displays the temperature. The control associated with tank temperature can provide the thermostat's SPST relay output to shut off engine circulation valve. The SPST output relay is insufficient to manage both the 'open' and 'close' signals of the CR02 type control. The thermostat relay will operate a separate DPDT relay to 'invert' both lines from the mode switch at 180F water temp and revert to normal at 170F. The relay control power will come directly from the engine valve's 'open' line so as to only allow 'invert' when the engine valve's is commanded open (Mode 1 & 4). While the engine valve is open in mode 4, coolant is not heating water so the thermostat will not be activated.

2) Coolant will circulated in any channel available so it must be prevented from circulating where it is not needed. There are two reasons for the 4 system control valves of the main loop; to open the required path and close any potential bypass. The cabin heat/freeze protection system similarly has 5 circuit paths, 3 heat exchangers in the cabin and 2 pipe loops through compartment/tanks. In this case, all 5 loops must operate simultaneously with each at an acceptable flow rate. This requires some means to modify resistance to flow in each of the 5 loops or the majority of coolant will go where there is least resistance. Each circuit will have a manual ball valve that will be partially closed to balance flow between circuits. I imagine this is something that gets tweaked several times initially but once 'balanced', does not need to be adjusted again. Because the freeze protection circuits can switch on an off while the cabin heat circuits remain on, I have made them of 3/8 tubing to only allow a small percentage of overall flow and hopefully not have a large negative affect on the system balance.

3) The freeze protection of the fresh tank and pump compartment will be achieved by allowing hot water from the calorifier to circulate (using the fresh water pump) from the shower water hot line, back to the tank through the hot line purge system, warming the water supply. The supply of heated water will only return to one tank so the return and supply valves must be set for that tank and the other tank should be empty/drained. The tanks and the pump compartment have temperature monitoring and any one below the temperature threshold will trigger hot water to be added to the tanks and circulated. The hydronic system diagram does not yet show the third ½" ball valve to be used for this. When the two temporary tanks are replaced by the single tank in the final design, this system will be simplified.

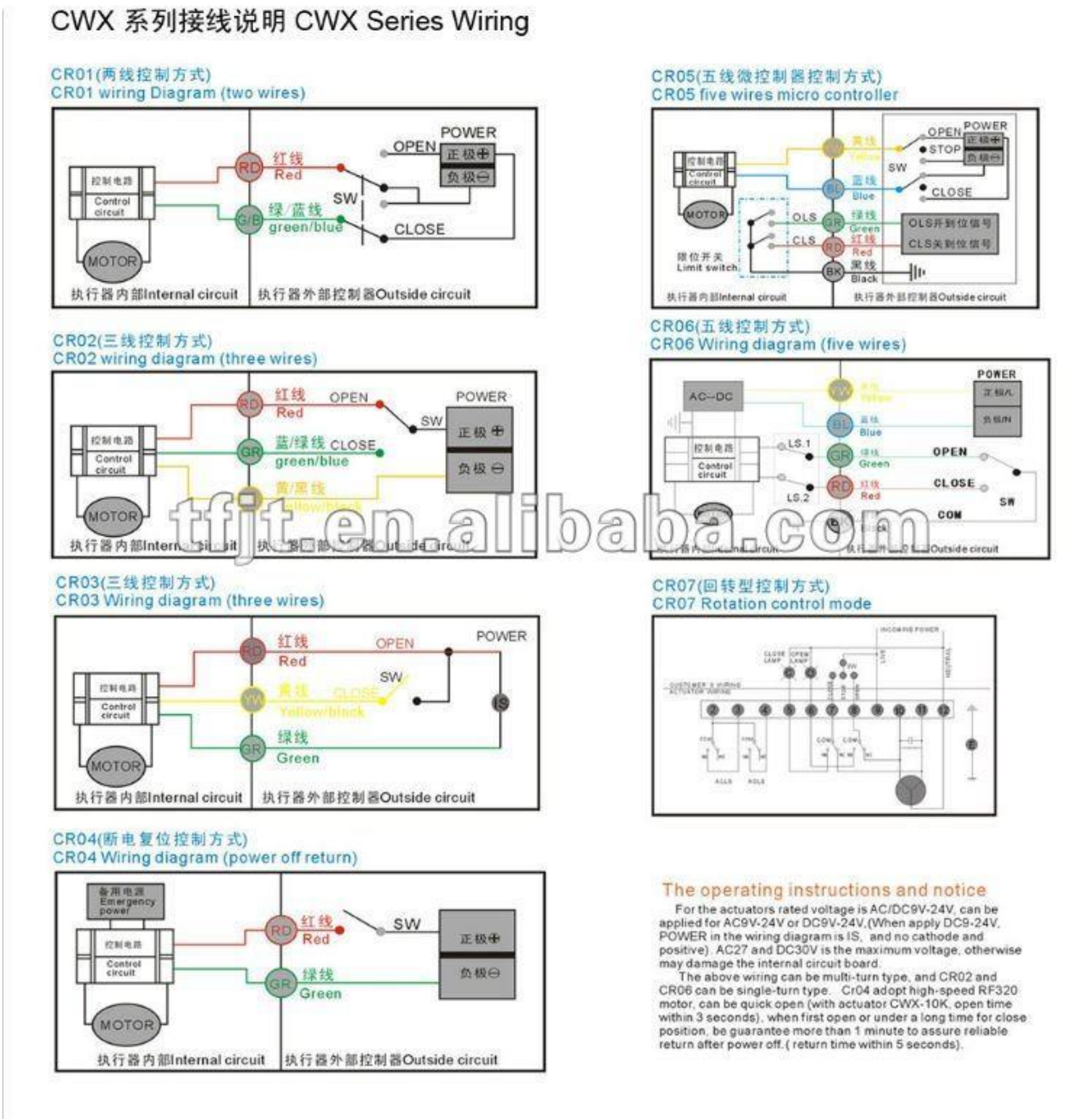
There is no cutoff or temperature regulation of water heating with the coolant heater. The coolant heater will always run at full capacity to deliver 180F coolant. As the water heats and accepts less and less heat from the coolant, warmer returning coolant results in the heater throttling down. When it reaches its lowest operating level and the coolant still returns hot, it will shut down. In most cases, it is unnecessary to heat the water tank to 180F. ~125F is likely adequate. Shutting off the coolant heater at any water temperature less than 180F must be done manually.

5) Heat dispersal into the cabin will be by 4 sources; looped ½" PEX tubing below the main cabin floor, natural convection of the towel heater/drying rack in the shower, fan coils in the bunk and below the kitchen sink. Depending on conditions, there may be a need for more

heat in one area and less in another or a need to equalize uneven heat delivery. These are the possibilities and how I imagine handling them;

- Uneven temperature in any area of the cabin: During system start-up, calibration of the coolant restriction valve on the main cabin loop/radiator will be adjusted to achieve near balance and could be changed it the balance is not maintained at different outdoor temperatures. The preferable method will be turn on the circulation duct in the false ceiling to mix air between the main cabin and bunk to maintain equal air temperature throughout the living area.
- High demand for clothes drying (shower radiator): I imagine this radiator having the least resistance of any radiator, thereby needing to have the regulating valve in the top rung of the radiator to be mostly closed in normal conditions. If there is a need for high drying, the regulating valve can be opened wide, allowing most of the coolant to flow through it.
- High demand for clothes drying without (or little) cabin heat; open the shower radiator fully and i) turn off radiator fans by switching off the fan blower override switches on either or both radiators, if that is insufficient, ii) stop the floor heating by closing the kitchen radiator/floor loop restrictor valve, noting its position to which it is to be returned.
- Need for domestic hot water while cabin heat is operating; The mode switch does not allow for both cabin heat and water heating simultaneously. While the coolant heater is operating, switch from cabin heat to water heating till water is as hot as necessary (monitor tank temperature). The calorifier only needs to heated to 130F to meet all domestic needs. I imagine that even in the coldest situation, switching from cabin heat to water heating would not allow the cabin temperature to decline unacceptably. If it does, switch between cabin heat and water heating several times for shorter periods to ameliorate cabin temperature drop.
- Need for freeze protection hot water while cabin heat is operating; The fresh tank freeze protection system relies on hot water in the calorifier but does not monitor its availability. If operating in frigid conditions, the calorifier should be heated periodically and should be reviewed each night before going to bed to ensure there is hot water available if the freeze protection system needs it. Manually shuttling between cabin heat and water heating will be necessary. In worst case circumstances, the electric backup freeze protection will come on.

Appendix B: Hydronic Valve Electrical Schematic



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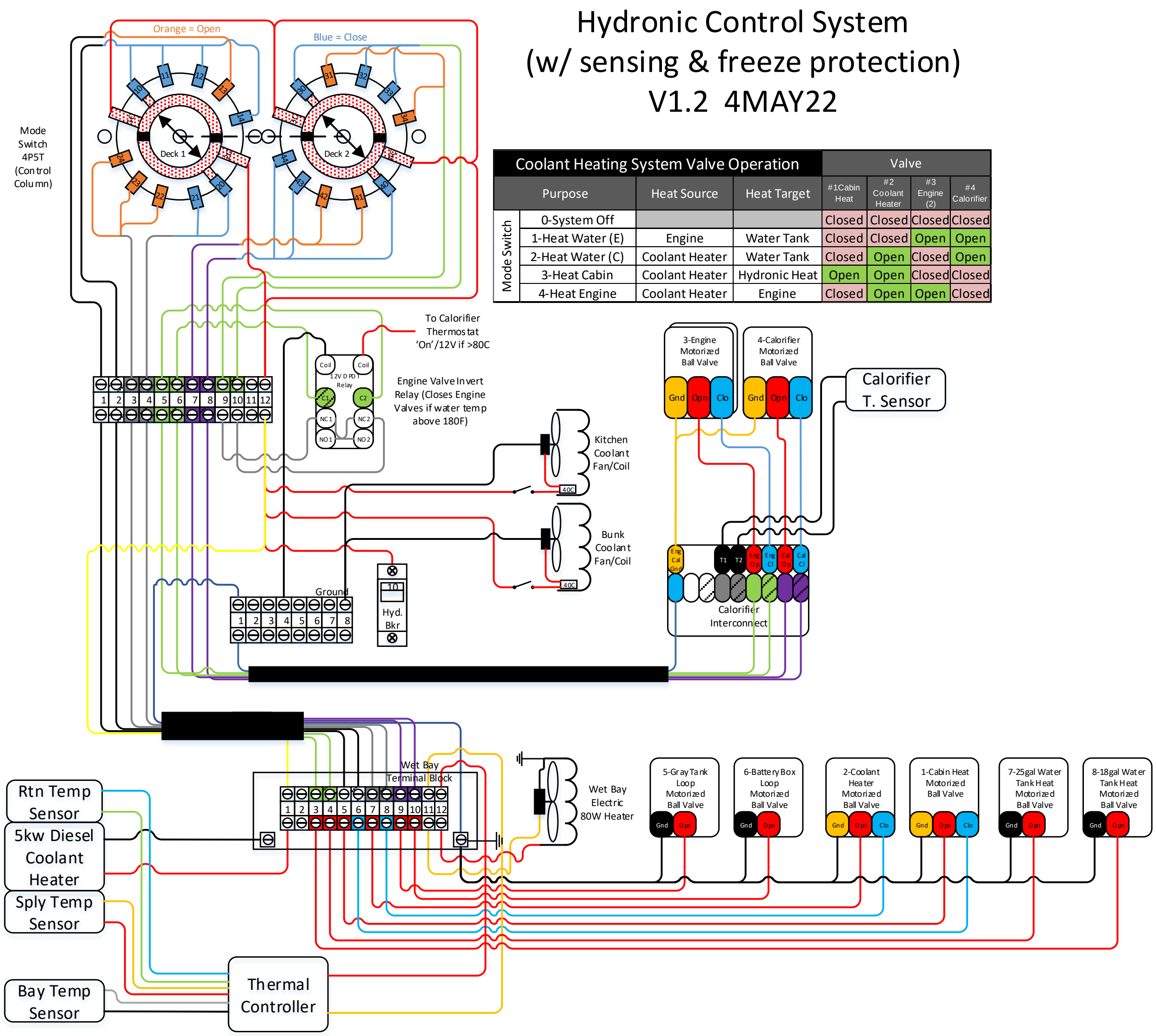

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	3-Heat Cabin	Coolant Heater	Hydronic Heat	Open	Open	Closed	Closed
	4-Heat Engine	Coolant Heater	Engine	Closed	Open	Open	Closed